Daily variation of carbon flux in soils of Populus euphratica forests in the middle and lower reaches of the Tarim River

Huang Xiang¹,², Chen Yaning¹**, Li Weihong¹, Ma Jianxin¹,² and Chen Yapeng¹,²

(¹ Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China; ² Graduate University, Chinese Academy of Sciences, Beijing 100039, China)

Accepted on September 19, 2006

Abstract In order to elucidate the daily variation of respiration in soils of Populus euphratica forests and analyze its relationship with environmental factors in the middle and lower reaches of the Tarim River, the LI-8100 instrument of soil CO₂ flux system was used to measure the parameters of soil carbon flux and air temperature 10 cm above ground surface along the profiles of Usyman, Arche River, Yengisu and Karday, and the relationships between the soil carbon flux and the soil moisture content were analyzed. The nonlinear regression analysis was carried out with the software SPSS13.0. We observed that: (1) soil respiration began to be restrained when the air temperature was up to 30°C 10 cm above the ground surface; (2) the rates of soil respiration under the forests of Populus euphratica were significantly different at various moisture contents; the soil carbon flux was high along the Usyman profile, which has a high soil moisture content, and it was low along the profiles of Arche River, Yengisu and Karday, which has a low soil moisture content; (3) the exponential model can be used to explain the relationship between soil respiration and air temperature 10 cm above the ground surface. The average Q₁₀ values along the profiles of Usyman, Arche River, Yengisu and Karday are 0.61, 0.16, 0.22 and 0.35 respectively, much lower than the average of the world; (4) there is a positive correlation between the soil carbon flux and the soil moisture content.

Keywords: Populus euphratica, soil carbon flux, air temperature 10 cm above ground surface, soil moisture content, the Tarim River.

Soil respiration is one of the most important processes in the carbon cycle of terrestrial ecosystems. The amount of CO₂ discharged by the soil respiration is only next to that fixed by the total photosynthesis of vegetation canopy¹. Therefore, the accuracy in measurement of CO₂ amount discharged by soil respiration is a key to assess the biological process of ecosystem². Carbon flux of soil has a close correlation with the environmental factors. The change of carbon flux of soil is mainly regulated by water content and temperature together³, and of which, an exponential model is commonly used for showing the change of soil inspiration along with temperature⁴–⁶. But the concrete association between humidity and soil respiration has not yet been established⁷–⁹. Previous studies have focused on the seasonal changes of soil respiration and the relationship between soil respiration and the factors of water and temperature at the anurelipidium Chinese prairie¹⁰ and half-arid prairie¹¹ of temperate zones, savanna of the north Australian¹² and tall-grass prairie of the North America¹³,¹⁴, a few on the Populus euphratica community in extremely arid regions¹⁵,¹⁶.

Populus euphratica is the major constructive species to the desert forest at the banks of Tarim River, and as the biggest natural Populus euphratica pool of resources in the world, it occupies 54% and 89% of the total Populus euphratica forest area of the world and China respectively. Intensified water resource development in Tarim River basin, which changed the water condition of the terrestrial ecosystem of the lower reaches greatly, resulted in a situation of no water in the lower reaches of Tarim River, crossing a 320 km distance. And it inevitably influenced the respiration of plant root system and the composition of microorganism community. In this case, the soil respiration of Populus euphratica community will also change consumingly. In addition, the middle and lower reaches of Tarim River are in the warm temperate zone, the differences in mean annual temperature and in mean daily temperature are great. The accumulated temperature, which is not lower than 10°C is mostly between 4100 and 4300°C

** Supported by Knowledge Innovation Important Direction Item of Chinese Academy of Sciences (Grant No. kaxx2-yw-127) and National Natural Science Foundation of China (Grant Nos. 90502004, 40671014)

** To whom correspondence should be addressed. E-mail: chenyln@ms.xjib.ac.cn
and lasts for 180—200 days, and the evaporation capacity, exceeds the rainfall precipitation greatly. All of these make this region an ideal location to study the law of the influence of temperature and humidity on soil respiration in extremely arid environments and to investigate the responses of root system and soil microorganism to climatic changes. Moreover, the study on the change of soil carbon flux and its influencing factors in this region is of importance to determine the function of this region as a source/sink in the carbon cycle.

1 Methods

1.1 Natural conditions of the region

Surrounding Taklimakan Desert, the main stream of Tarim River spans 1321 km. The region of interest is located in the middle and lower reaches of the main stream of the Tarim River from Yingbaah to Taiteka Lake (41°00′—39°47′N, 85°21′—88°22′ E) (Fig. 1), which is in the warm temperate zone, belonging to the arid desert climate with wind-drifting sand, floating dust, long sunshine duration and big temperature difference with the annual mean diurnal range of 14—16°C and the annual maximum diurnal range above 25°C. The annual mean temperature variability is 0.5°C from the middle reaches to the lower reaches of the river, and the yearly precipitation reduces from 41 mm at the middle reaches to 25 mm at the lower reaches, the yearly evaporation capacity increases from 2778 mm at the middle reaches to 2906 mm at the lower reaches, and the aridity index increases gradually from the middle reaches to the lower reaches. The physical makeup at the ground surface consists of fine sandy loam and the major constructive species are Populus euphratica and Tamarix spp.

1.2 Experimental methods

The experiments were conducted during a period of September 1—20, 2005. Four observation sections were set at Usman and Archy River along the middle reaches and at Yingsu and Kerdayl along the lower reaches. At each section, a sampling area was defined near the monitoring well of groundwater, where five PVC collars were inserted 8 cm deep into the ground in a plum blossom pattern so that five duplications of the measurements of soil carbon flux using the LI-8100 automated soil CO₂ flux system could be obtained. The soil samples were taken for the measurements of diurnal variation with regard to the soil respiration of the major constructive species, Populus euphratica community. Soil respiration was monitored from 8 am to 8 pm with an interval of 2 hours. Simultaneously, the air temperature within the Populus euphratica community was measured with a psychrometer and the 10 cm-above-ground air temperature was real-time monitored with WMY-01C digital temperature measuring meter. Due to the fact that underground water and soil moisture did not change much within one day in the arid area, both of them were observed within a single day, and soil samples at the depth of 5—15 cm were collected to measure the soil moisture content with the drying method. All statistical data were analyzed with SPSS13. 0 software, and the difference in diurnal variation of soil respiration of Populus euphratica community at various sections was analyzed for multiple comparisons with AVOVA program. Non-linear regression program was used to analyze the relationship between soil carbon flux and air temperature at 10 cm above ground. The exponential model used is: \[ R_s = a e^{bT} \], where \( R_s \) refers to soil respiration; \( T \) is temperature; \( a \) is soil respiration at 0°C which is also called the basic respiration by some researchers; \( b \) is temperature response coefficient which reflects how sensitive the response of soil respiration to temperature is. In fact, the first power exponent model \( Q_{10} \) is commonly used.

![Fig. 1. Schematic of monitoring locations and sections at the middle and lower reaches of Tarim River.](image)
The $Q_{10}$ value could be determined by $Q_{10} = e^{10b}$, in which $b$ is as the same as above. The non-linear program was used to analyze the relationship between the average soil respiration of various communities and temperature, also the relationship between $Q_{10}$ and temperature.

Fig. 2. Soil carbon flux and air temperature at 10 cm above the ground surface at each section. (a) Usman; (b) Archy River; (c) Yingxiu; (d) Karday.

2 Result and analysis

2.1 Diurnal variation of soil respiration and air temperature near the ground surface

The average values of five-duplication of soil carbon flux and the average values of air temperature at 10 cm above the ground surface at each monitoring section were used for the presentation of the results illustrated in Fig. 2.

It can be seen from this figure that the diurnal variation is fairly consistent and the values of soil carbon flux are relatively small within a range of 0.02—0.9 $\mu$mol·m$^{-2}$·s$^{-1}$, although the ranges of air temperature change near the ground surface at the sections are not completely same. However, there are still some differences in the scope of the change and diurnal variation dynamics because of the different zones, i.e. the maximum carbon flux at the middle reaches appeared at 14:00 with reversal trend after that time, but the carbon flux at the lower reaches arrived at the maximum value at 12:00 and then the soil respiration was restrained and declined; the air temperature near the ground surface exceeded 30°C at 14:00 at the middle reaches and at 12:00 at the lower reaches respectively, which shows that the soil respiration was restrained when the air temperature reached 30°C. Usman and Archy River both are located at the middle reaches of Tarim River and Yingxiu and Kerdayi the lower reaches of Tarim River. The change of carbon flux of soil respiration at the middle reaches was $0.16-1.29$ $\mu$mol·m$^{-2}$·s$^{-1}$, and at the lower reaches was $0.09-0.39$ $\mu$mol·m$^{-2}$·s$^{-1}$. The average carbon flux was $0.49$ $\mu$mol·m$^{-2}$·s$^{-1}$ at the middle reaches and $0.19$ $\mu$mol·m$^{-2}$·s$^{-1}$ at the lower reaches. In the case that both carbon fluxes are not very big, the value at the middle river reaches would be bigger than that at the lower reaches, and for the vegetation coverage at the middle reaches is greater than that at the lower reaches. The result of linear regression analysis indicated that the exponential model fitted the relationship well between soil respiration and air temperature near the ground surface at every cross section ($R^2 = 0.6796-0.9418$, significance < 0.0002—0.0228), and of which, the correlation at Archy River section is best ($R^2 = 0.9418$,}
significance = 0.0002) (Fig. 3). \( Q_{10} \) is a temperature-sensitive index of the soil respiration\(^{[16]} \). The values of \( Q_{10} \) at the four sections are 0.61 at Usman, 0.16 at Archy River, 0.22 at Yingsu, and 0.35 at Kerdai, that means that, with every 10°C rise of the air temperature at 10 cm above the ground surface, the rate of soil respiration at the four sections would increase respectively by 0.61, 0.16, 0.22 and 0.35 times, all are far lower than the worldwide average level (2.4), also lower than of the forestry community at the adjacent latitude (43°N, 121°E) and that of temperate grassland (43°N, 115°E). This shows that the sensitivity of soil respiration to temperature in the investigated region is far lower than those in other areas.

![Graphs showing the relationship between soil carbon flux and air temperature](image)

**Fig. 3.** Relationship between soil carbon flux and air temperature above the ground surface at each section. (a) Usman, (b) Yingsu, (c) Archy River, (d) Kerdai.

### 2.2 Relationship between soil respiration and soil moisture content

The variance analysis indicated that the population difference in the daily change of soil respiration of *Populus euphratica* community at each section was extremely remarkable during the whole monitoring period (significance = 0.000). The soil carbon flux at Usman was the biggest one (1.56 \( \mu \text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \)), which was 4.2 times and 0.6 times of that at the lower reaches (Yingsu and Kerdai) respectively. The multiple comparison result demonstrated that the significances of difference at various sections are not consistent. Generally speaking, the carbon flux at Usman section with larger soil moisture content was higher than the values at Archy River, Yingsu and Kerdai sections where the soil moisture content was relatively low.

Water is the most significant environmental factor affecting the ecosystem in arid areas\(^{[18]} \), therefore, even the slight improvement of soil water can remarkably change the plant root system and the microorganism’s activity. Thus soil moisture becomes a determinant to the diurnal variation of carbon flux. By comparison of 10 samples collected at each section a similar tendency of both the soil carbon flux and the soil moisture content was found. The peak and the valley-bottom values of soil carbon flux were nearly in the same phase with the change of soil moisture content (Fig. 4(a)), which suggests a close relation between soil moisture content and carbon flux. In addition, nonlinear regression analysis showed the exponential model fits the relationship between the soil respiration of each community and the water moisture content at 5—15 cm depth (\( R^2 = 0.5377 \), significance = 0.016) (Fig. 4(b)).
that the soil respiration is insensitive to the change of temperature in the region we studied during the experimental period. Wildung et al.\textsuperscript{[11]} studied the soil respiration of the half-arid prairie area at Washington of east US, and found out that the influence of temperature on soil respiration reduced to be the secondary factor when the temperature exceeded 15\textdegree C. Chen et al.\textsuperscript{[19]} also found that the exponential model we used fits better at low temperature than at high temperature when he studied the response of soil respiration of 11 plant communities in the temperate-zone prairie to the air temperature in summer and autumn. The temperature at the middle and lower reaches of Tarim River generally exceeds 15\textdegree C, so it is reasonable that the $Q_{10}$ value is small under such a high temperature condition.

Water is one decisive factor for the plant to survive under the extremely arid condition. When the temperature is high, the limit of water content condition will reduce the capacity of soil respiration that should rise along the rise of temperature\textsuperscript{[24,25]}. The soil carbon flux and the soil moisture content were related closely with each other in this area, which matches those results about the seasonal arid prairie at north Queensland in Australia\textsuperscript{[26]}, tall-grass prairie in North America\textsuperscript{[13,14]}, and aneurolepidium chinesen prairie in the Xinlin River basin\textsuperscript{[20]}. Parker et al. studied the soil respiration of one arid grazing meadow and found that the activation energy of soil respiration changed from 84.9 kJ\cdot mol\textsuperscript{-1} to 39.5 kJ\cdot mol\textsuperscript{-1} when the dry soil became humid, which indicated that the sensitivity of soil respiration to temperature increased along with the increase of soil water\textsuperscript{[27]}. In our study, the $Q_{10}$ value also increased from 0.35 to 0.61 when the soil moisture content increased from 0.88\% to 22.63\%, which indicates that the sensitivity of soil respiration to the temperature tended to increase with the rise of soil moisture content. Thus the soil inspiration in the arid area also is influenced by the conditions of the soil moisture content. But the relationship between the soil respiration and the soil moisture content at different research sites has not been confirmed. Chen et al. used the linear model to fit the relationship between soil respiration and soil moisture content at typical degraded prairie community of Xinlin River basin. We used the exponential model to address the relationship between the soil carbon flux and the soil moisture content because the annual mean evaporation capacity is 48 times of the an-

3 Discussion

In the study of the relationship between the seasonal change of soil respiration and environmental factors, the researchers are accustomed to use the exponential model $Q_{10}$ value to explain the change of soil respiration along with the air temperature and ground temperature\textsuperscript{[14-6]}. This method has been widely used in the studies at temperate-zone half-arid aneurolepidium chinense prairie\textsuperscript{[10,19,20]}, savanna\textsuperscript{[12]} and half-arid prairie area in south US\textsuperscript{[21]}. And in this study, the exponential model also fits the response of soil respiration to the change of temperature at every section of Populus euphratica community.

We found that all the values of soil carbon flux at every section in the studied area were small, probably because some oxygen metabolism-related enzymes in the plant root system and in the edaphon were inactivated when the temperature exceeded a certain limit\textsuperscript{[22]}. The soil carbon flux reduced gradually at four sections when the 10 cm-above-ground air temperature exceeded 30\textdegree C, which is the so-called thermal adaptation phenomenon\textsuperscript{[23]}, namely low $Q_{10}$ value at high temperature and high $Q_{10}$ value at low temperature\textsuperscript{[24]}

The worldwide average $Q_{10}$ value is 2.4, but all the $Q_{10}$ values at the four sections in our study were smaller than the worldwide average value, indicating...
nual mean rainfall in the arid area, and the water in soil mainly comes from surface runoff and ground wa-
ter absorbed by vegetation root system. Under the
conditions of high temperature and aridity, the effect
of temperature on the soil respiration is not as strong
as moisture content does.

In the past over 100 years, the measuring method
and technology regarding soil inspiration have
been improved constantly from the in situ mensura-
tion to the static and dynamic mensurations28,29. Am-
ong them, the alkali absorption method is widely
used at present, which can monitor soil respiration at
several sites in a field simultaneously to obtain the
data of the soil respiration on a larger temporal and spa-
tial scale. However, it prevents the gas inside the ob-
servation body from exchanging with the air outside,
disturbing the natural state. In our study, we used
infrared method with the LI-8100 automated soil CO2
flux system to monitor the soil respiration. This in-
strument has an exhaust pipeline to reduce pressure,
which keeps the pressure balance between the air
chamber and the atmosphere and reduces the error
cased by "the air chamber effect". This method is
simple, fast and precise, but the equipment required
is expensive, which limits the big-scaled measurement
of soil respiration.

In this study, we only explored the effect of di-
urnal variation of soil respiration and air temperature
at 10 cm above the ground surface on the soil moisture
content at four experimental sites for a period of 20
days. In fact, total soil respiration involves several bi-
ological and non-biological processes. Therefore, the
factors like soil organisms, plant root systems, vege-
tation coverage and soil nutrient etc. could influence
directly or indirectly the soil respiration rate, to dif-
ferent extents, when the conditions of water or heat
change. Under certain conditions, those factors even
conceal or revise the influence of water and heat on
soil respiration. On the other hand, the influences of
those factors on soil respiration will be appeared only
after a long time, so a long-term and continuous moni-
toring of their influences on the soil respiration of
Populus euphratica communities at the desert banks
of the Tarim River, is needed to reveal the true pro-
file of soil respiration in this region on a greater tem-
poral scale.

4 Conclusions

(1) For the Populus euphratica communities at
the middle and lower reaches of Tarim River, the di-
urnal variation curve of CO2 emissions in the soil had a
single peak. The maximum values of carbon flux pre-
sented at 14:00 at the middle reaches with a reversal
trend, but at the lower reaches, the value of soil res-
piration was restrained and began to drop after the
peak at 12:00. The study revealed a close relation-
ship between soil carbon flux and air temperature near
the ground surface, which is also affected by the ve-
egation coverage.

(2) In Tarim River basin, the air temperature
near the ground surface is an important factor to de-
cide the soil carbon flux of Populus euphratica com-
munities, and the exponential model fits well the rel-
ationship between the soil respiration of communities
and the air temperature at 10 cm above the ground
surface at each sections.

(3) The Q10 values of four sections at the middle
reaches and lower reaches of Tarim River were calcul-
ated as: 0.61 for Usman, 0.16 for Archy River,
0.22 for Yingxiu and 0.35 for Kerday. All of them
are far lower than that of the worldwide average and
that of the forest and the prairie community at adja-
cent latitude, which indicates that the sensitivity of
soil respiration to temperature in this area is far lower
than that in other areas.

(4) The changes of soil carbon flux and soil
moisture content showed a similar tendency at the
middle and lower reaches of Tarim River, which indi-
cates that the soil moisture content has an important
effect on soil respiration, and the exponential rela-
tionship fits them well.

(5) In the Populus euphratica communities at
the middle and lower reaches of Tarim River, the sen-
sitivity of soil respiration to temperature tends to
increase with the enlargement of soil moisture con-
tent, which indicates that the sensitivity of soil respi-
ratation to temperature is still affected by the condition
of soil moisture content under the arid condition.

Acknowledgements The authors thank Liu Guohua at
Ecological Environment Research Center, Chinese Academy
of Sciences, for his comments and suggestions; thank Ding Hui,
Zhou Xiaoming, He Bin, Hao Xingming for their assisting in
the field work with measuring the temperature.

References

1 Raich JW and Schlesinger WH. The global carbon dioxide flux in
soil respiration and its relationship to vegetation and climate. Tellus,
1992, 44B: 81—99
3 Singh JS and Gupta SR. Plant decomposition and soil respiration in terrestrial ecosystems. Botanical Review, 1977, 43: 419—528
6 Ohashi M, Gyokuse K and Saito A. Contribution of root respiration to total soil respiration in a Japanese cedar (Cryptomeria japonica D. Don) artificial forest. Ecological Research, 2000, 15: 323—333
11 Wildung RE, Garland TR and Bunchboom RL. The interdependent effects of soil temperature and water content on soil respiration rate and plant root decomposition in arid grassland soils. Soil Biology & Biochemistry, 1975, 7: 373—378
22 Fang C and Moncrieff JB. The dependence of soil CO₂ efflux on temperature. Soil Biology and Biochemistry, 2001, 33: 155—165
25 Kirschbaum MUF. Will changes in soil organic carbon act as a positive or negative feedback on global warming? Biochemistry, 2000, 48: 21—51